

We claim:

1 1. A magnetic device comprising:

2 a pinned magnetic layer with a magnetization vector with a fixed magnetization direction;

3 a free magnetic layer with at least one magnetization vector with a changeable
4 magnetization direction;

5 a first non-magnetic layer that spatially separates said free magnetic layer and said pinned
6 magnetic layer such that the mutual magnetic interaction between said free magnetic layer and said
7 pinned magnetic layer is minimized;

8 a read-out magnetic layer with a magnetization vector with a fixed magnetization direction;

9 and

10 a second non-magnetic layer that spatially separates said free magnetic layer and said read-
11 out magnetic layer such that the mutual magnetic interaction between said free magnetic layer and
12 said read-out magnetic layer is minimized.

1 2. The magnetic device according to claim 1, wherein one of said magnetization directions
2 of said pinned magnetic layer, said free magnetic layer, and said read-out magnetic layer lies along
3 an axis which is different than at least one of axes along which said other magnetization directions
4 lie.

1 3. The magnetic device according to claim 1, wherein:

2 said fixed magnetization direction of said pinned magnetic layer is perpendicular to a plane
3 of said free magnetic layer; and

4 said changeable magnetization direction of said free magnetic layer is perpendicular to an
5 axis extending longitudinally through said magnetic device.

1 4. The magnetic device according to claim 1, wherein said changeable magnetization
2 direction of said free magnetic layer and said fixed magnetization direction of said read-out layer
3 switch between being in anti-parallel alignment and parallel alignment.

1 5. The magnetic device according to claim 1, wherein said free magnetic layer has a single
2 magnetization vector with a changeable magnetization vector.

1 6. The magnetic device according to claim 1, wherein said magnetization direction of said
2 magnetization vector of said free magnetic layer represents a bit of information.

1 7. The magnetic device according to claim 1, wherein:
2 said magnetic device is pillar-shaped; and
3 said pinned magnetic layer, said first non-magnetic layer, said free magnetic layer, said
4 second magnetic layer, and said read-out magnetic layer are less than approximately 200 nm
5 laterally and approximately 1 nm to 50 nm thick.

1 8. The magnetic device according to claim 1, wherein said pinned magnetic layer, said free
2 magnetic layer, and said read-out magnetic layer are comprised of a member of the group
3 consisting of Co, Ni, Fe, an alloy of Co and Ni, an alloy of Co and Fe, an alloy of Ni and Fe, an
4 alloy of Co, Ni, and Fe, and permalloy $Ni_{1-x}Fe_x$.

1 9. The magnetic device according to claim 1, wherein said pinned magnetic layer, said free
2 magnetic layer, and said read-out magnetic layer are comprised of a non-magnetic metal and a
3 member of the group consisting of an alloy of Co and Ni, an alloy of Co and Fe, an alloy of Ni
4 and Fe, an alloy of Co, Ni, and Fe, such that said non-magnetic metal and said member are
5 ferromagnetically ordered at room temperature.

1 10. The magnetic device according to claim 9, wherein said non-magnetic metal is a
2 member of the group consisting of Cu, Pd, and Pt.

1 11. The magnetic device according to claim 1, wherein said pinned magnetic layer, said
2 free magnetic layer, and said read-out magnetic layer are comprised of a member of the group
3 consisting of NiMnSb and a conducting magnetic oxide.

1 12. The magnetic device according to claim 11, wherein said conducting magnetic oxide is
2 either CrO₂ or Fe₃O₄.

1 13. The magnetic device according to claim 1, wherein said non-magnetic layers are
2 comprised of at least one member of the group consisting of Cu, Cr, Au, Ag, and Al.

1 14. A memory system comprising:
2 a memory cell comprising:
3 a pinned magnetic layer with a magnetization vector with a fixed magnetization
4 direction;

a free magnetic layer with at least one magnetization vector with a changeable magnetization direction;

a first non-magnetic layer that spatially separates said free magnetic layer and said pinned magnetic layer such that the mutual magnetic interaction between said free magnetic layer and said pinned magnetic layer is minimized;

a read-out magnetic layer with a magnetization vector with a fixed magnetization direction; and

a second non-magnetic layer that spatially separates said free magnetic layer and said read-out magnetic layer such that the mutual magnetic interaction between said free magnetic layer and said read-out magnetic layer is minimized; and

an electric current source connected to said pinned magnetic layer and said read-out magnetic layer so that an electric current can traverse said memory cell.

15. The memory system according to claim 14, wherein one of said magnetization directions of said pinned magnetic layer, said free magnetic layer, and said read-out magnetic layer lies along an axis which is different than at least one of axes along which said other magnetization directions lie.

16. The memory system according to claim 14, further comprising a means for measuring the resistance between said pinned magnetic layer and said read-out magnetic layer.

17. The memory system according to claim 16, wherein said resistance measuring means comprises a voltmeter connected to said pinned magnetic layer and said read-out magnetic layer.

1 18. The memory system according to claim 14, wherein said electric current comprises a
2 single current pulse.

1 19 The memory system according to claim 14, wherein said electric current comprises two
2 current pulses wherein one of said two current pulses is a negative current pulse and the other of
3 said two current pulses is a positive current pulse.

1 20. The memory system according to claim 14, wherein said electric current is applied in
2 a sub-nanosecond period of time.

1 21. A method of magnetic switching using current-induced spin-momentum transfer, said
2 method comprising the steps of:

3 applying an electric current to a magnetic device, wherein said electric current comprises
4 two current pulses wherein one of said two current pulses is a negative current pulse and the other
5 of said two current pulses is a positive current pulse; and

6 stopping said electric current when a magnetization vector of said magnetic device has
7 rotated 180° while said electric current is applied.

1 22. The method according to claim 21, wherein said current applying step occurs in a sub-
2 nanosecond period of time.

1 23. A method of making a memory cell, said method comprising the steps of:

2 forming a first non-magnetic layer on a pinned magnetic layer, said pinned magnetic layer
3 having a magnetization vector with a fixed magnetization direction;
4 forming a free magnetic layer with at least one magnetization vector with a changeable
5 magnetization direction on said first non-magnetic layer;
6 forming a second non-magnetic layer on said free magnetic layer; and
7 forming a read-out magnetic layer with a magnetization vector with a fixed magnetization
8 direction on said second non-magnetic layer;
9 wherein said first and said second non-magnetic layers minimize the mutual magnetic
10 interaction between said pinned magnetic layer, said free magnetic layer, and said read-out
11 magnetic layer.

1 24. The method of making a memory cell according to claim 23, wherein one of said
2 magnetization directions of said pinned magnetic layer, said free magnetic layer, and said read-out
3 magnetic layer lies along an axis which is different than at least one of axes along which said other
4 magnetization directions lie.

1 25. The method of making a memory cell according to claim 23, further comprising the
2 step of:
3 connecting an electric current source to said pinned magnetic layer and said read-out
4 magnetic layer so that an electric current can traverse said memory cell.

1 26. The method of making a memory cell according to claim 23, further comprising the
2 step of:

measuring the resistance between said pinned magnetic layer and said read-out magnetic layer.

27. The method of making a memory cell according to claim 26, wherein said resistance measuring step comprises the step of connecting a voltmeter to said pinned magnetic layer and said read-out magnetic layer.

28. The method of making a memory cell according to claim 23, wherein said pinned magnetic layer, said free magnetic layer, and said read-out magnetic layer are comprised of a member of the group consisting of Co, Ni, Fe, an alloy of Co and Ni, an alloy of Co and Fe, an alloy of Ni and Fe, an alloy of Co, Ni, and Fe, and a permalloy $\text{Ni}_{1-x}\text{Fe}_x$.

29. The method of making a memory cell according to claim 23, wherein said pinned magnetic layer, said free magnetic layer, and said read-out magnetic layer are comprised of a non-magnetic metal and a member of the group consisting of an alloy of Co and Ni, an alloy of Co and Fe, an alloy of Ni and Fe, an alloy of Co, Ni, and Fe, such that said non-magnetic metal and said member are ferromagnetically ordered at room temperature.

30. The method of making a memory cell according to claim 29, wherein said non-magnetic metal is a member of the group consisting of Cu, Pd, and Pt.

1 31. The method of making a memory cell according to claim 23, wherein said pinned
2 magnetic layer, said free magnetic layer, and said read-out magnetic layer are comprised of a
3 member of the group consisting of NiMnSb and a conducting magnetic oxide.

1 32. The method of making a memory cell according to claim 31, wherein said conducting
2 magnetic oxide is either CrO₂ or Fe₃O₄.

1 33. The method of making a memory cell according to claim 23, wherein said non-
2 magnetic layers are comprised of at least one member of the group consisting of Cu, Cr, Au, Ag,
3 and Al.